

Electromechanical Materials And Devices

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LONG TERM GOALS

The goals are: 1) improve the understanding of processing and performance of electroactive materials through synthesis, test, and modeling; 2) develop new materials for use in challenging environments, and 3) build proof-of-principle devices with enabling performance.

OBJECTIVES

The first objective is to provide a fully integrated group of techniques for direct measurement of electroactive materials under conditions of practical use. These will concentrate on properties with engineering and design relevance to materials fabricators and transducer designers. Our second objective is the determination of the ultimate properties, i.e., strain, hysteresis, and coupling, of polycrystalline materials under diverse conditions. Thirdly, we seek to improve processing and densification methods to further enhance performance. In the modeling area, our objectives are to apply advanced numerical methods (FEM and BEM) to determine the effects of material variation, e.g., second phases and internal components, on the performance and reliability of test devices. With regard to devices, we will explore the usefulness of free-form device fabrication and negative Poisson ratio materials for passive and active devices.

APPROACH

Our effort includes an experienced group of core faculty with strong support from the largest ceramic school in the United States. Overall direction is provided by Dr. Steven M. Pilgrim who has eleven years experience concentrating on composite hydrophones and electrostrictive projectors at both Martin Marietta Laboratories and NYSCC. The piezoelectric, free-form, and hydrostatic interests are directed by Dr. Walter A. Schulze. Modeling expertise resides with Dr. William B. Carlson. Correlation of macroscopic properties with the lattice response is under investigation by Dr. Scott T. Mixture. Additional insight into Navy needs and applications has been provided by Dr. Kurt M. Rittenmyer, formerly of NRL/USRD, who served as a research staff member. New efforts in electrodes and joining were begun under the direction of Dr. Doreen Edwards (transparent electrodes) and Dr. Alan Meier (direct joining of transducer plates). Additional efforts by other faculty and/or funding sources augment the core team listed. The majority of work is performed by US undergraduate and graduate students in association with the faculty and technical staff.

WORK COMPLETED

During this second complete contract year, the major pieces of equipment have been put to use. Staffing has been stabilized (18 graduate students, 15 undergraduates, and a member of the technical staff). The improved characterization capabilities have generated significant interest from companies (3 new corporate projects have begun). The first thin film efforts in the clean room were included in a

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5/98 MS Thesis. Broad improvements in measuring capability, including new and more precise methods for dielectric aging and modulus with applied field have been published. Last year's cryogenic samples showed strains consistent with the dielectric properties; however, the transition temperatures were too high. The second and third compositional suites reveal much lower transitions on our improved characterization apparatus. Piezotensegrity is being applied to sensors. Strong evidence of an acicular Ba-niobate phase has been found. This material may be suitable for seeded growth of textured ceramics—a possible alternative to single crystals for some uses. Theoretical comparisons of various hydrophone technologies and figures of merit has been made and submitted for publication. Improved modeling of stress and voltage distributions for multilayer devices (transducers and capacitors) has been completed. Dielectric characterization and x-ray diffraction apparatus have been modified to cover the range: 10 K to 1400 K.

Professors Meier and Edwards have been added to the participating faculty. Dr. Alan Meier is a metallurgist with interests in electroding and joining. He is supervising a project focused on direct bonding of electroactive materials—removing the need for a low stiffness polymer interlayer. Dr. Doreen Edwards expertise lies in the areas of transparent electrodes and impedance spectroscopy. Their work serves as a potential bridge to electro-optic and photonic sensors—possibly encompassing the interests of the 22-member Center for Glass Research at Alfred University. Both add to the thrust in fabrication and complement the mechanical and optical device interests.

TECHNICAL RESULTS

Major results were achieved in

ix areas during FY98: cryogenic measurements (dielectric and electromechanical), cryogenic materials, electromechanical characterization, material development, *in-situ* neutron and x-ray diffraction, and piezotensegrity. DiAntonio and Eitel extended the temperature range for measurable dielectric and electromechanical responses (see Figures 1 and 2).

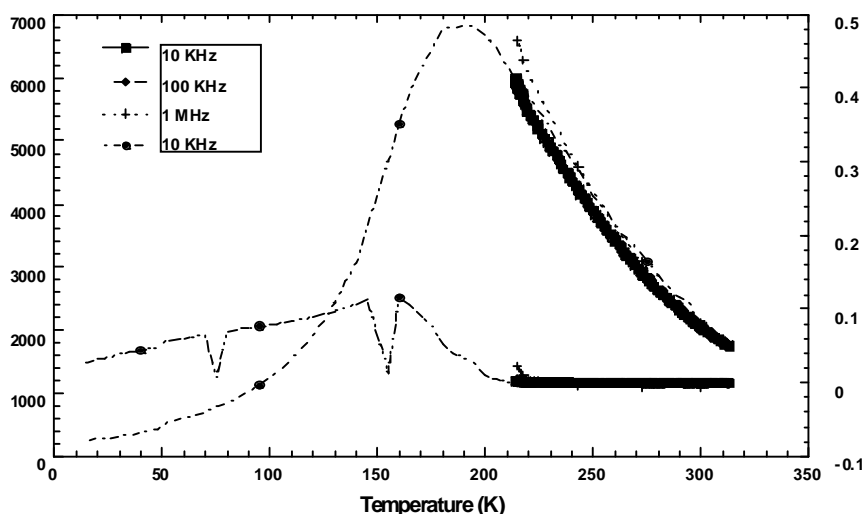


Figure 1. Dielectric response of $\text{PbMg}_{1/3}\text{Ta}_{2/3}\text{O}_3$ in the cryogenic temperature regime.

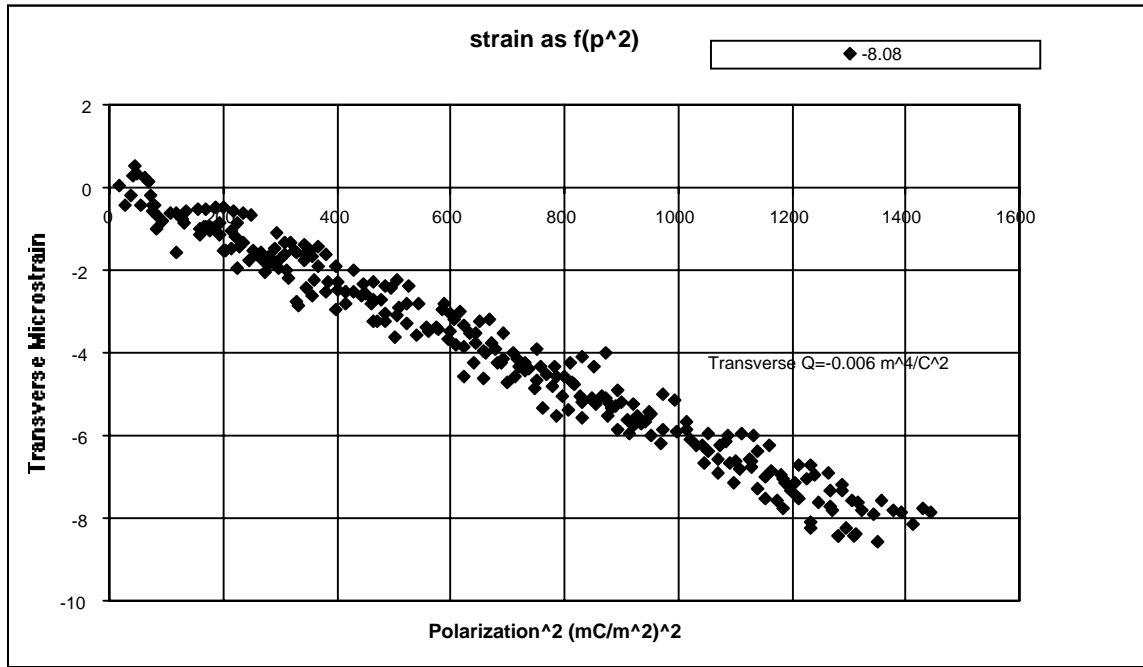


Figure 2. Simultaneous measurement of strain and polarization can be used to determine the electrostrictive coefficients ($\text{Pb}(\text{Mg}_{1-x}\text{Ni}_x)_{1/3}\text{Ta}_{2/3}\text{O}_3$ at -238°C and ± 1 MV/m and 1 Hz).

Phase pure perovskites of $\text{K}(\text{Ta}_{1-x}\text{Nb}_x)\text{O}_3$ AND $\text{Pb}(\text{Fe}_{2/3}\text{W}_{1/3})\text{O}_3$ were also made using novel processing routes to avoid pyrochlore formation. Figure 3 is an x-ray pattern of KTN ($x=0.80$) taken over the 2θ range of 5° to 80° and at a count time of 10 seconds. This pattern shows no indication of peak broadening or smoothing at the base of the peak due to second phases. At higher precision, Figure 4, the (200), (210), and (211) peaks indicates that the powder is either homogeneous (comprised of only a solid solution of KTaO_3 - KNbO_3) or that the dopant level is so small that any minor phases are below the detection limits.

Leary determined practical methods to measure: high-field aging (Figure 5), the field dependence of modulus (Figure 6), the harmonic corrected energy dissipation of an electroactive material (reference), and the electromechanical coupling (reference).

McKinney, Altizer, and Winn provided additional data on Ba-niobates, ruthenates, and ferroelectric films. McKinney has shown the existence of an acicular barium niobate that be suitable as a template for single crystal growth.

Neutron diffraction, under Misture, is maturing, with the first results taken under applied field and prestress. Piezoetensegrity, a concept originating with Carlson, is being applied to novel sensor and actuator devices that incorporate negative Poisson-type structures.

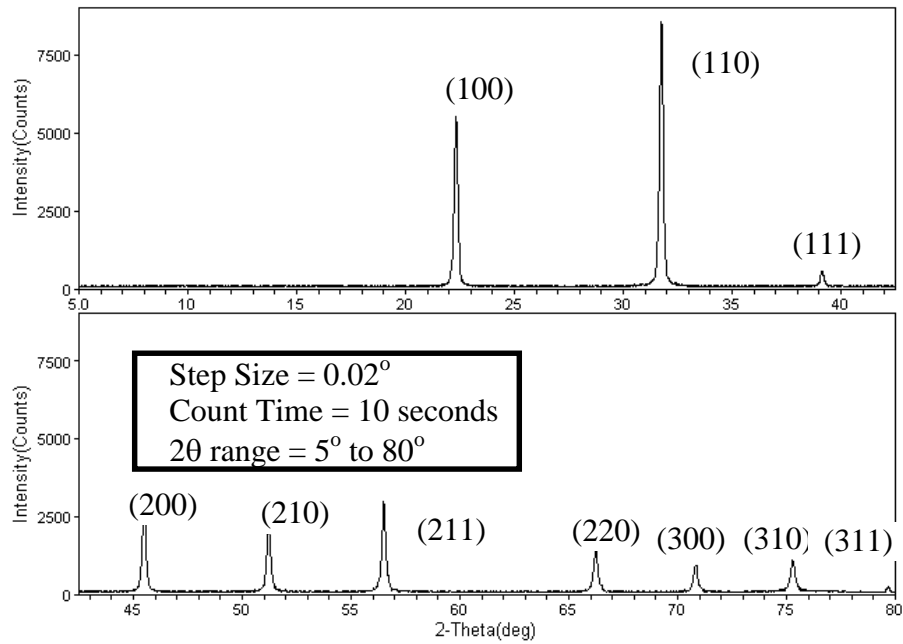


Figure 3. XRD pattern of KTN ($x=0.80$).

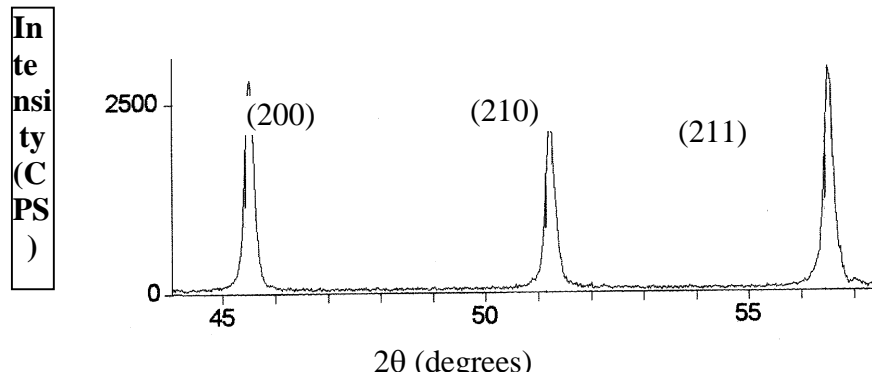


Figure 4. The (200), (210), and (211) peaks of the shown in Figure 3.

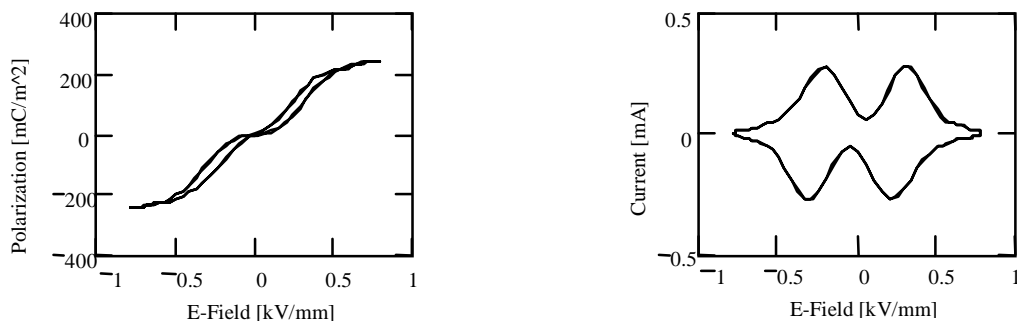


Figure 5. High-field aging in a PMN-PT-ST at 1 Hz after 5 days (from Leary 1998). Displaying a more sensitive determination of aging than weak-field analysis.

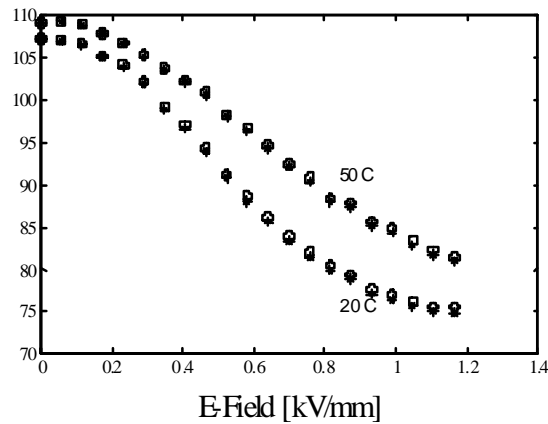


Figure 6. *Young's modulus decreased ~30 % with fields near 1 kV/mm. '*' represents the calculation of Y assuming Y_{long} to be independent of field. 'o' represents the calculation of Y considering the stiffening of Y_{long} . Sample: PMN-PT-ST.*

TRANSITIONS

The primary effort remains at the 6.1 level. However, some effort has transitioned. The demonstrated promise of reticulated hydrophones has led Lockheed-Martin to begin examining them as a potential replacement for PVDF in towed arrays. The measurements capability and software has been used by several entities: MPM Inc., Lockheed-Martin OR&SS, Lockheed-Martin Missiles and Space, AST Inc., with several other pending users.

RELATED PROJECTS

The project most closely related is Maximizing Electrostrictive Response N00014-98-1-0230PMN. An AASERT effort, "Coupling and Power Determination in Electrostrictive Materials N00014-97-1-0674" began late in FY97 with ONR 321SS. The 'PMN Chapter' for The Navy Transducer Handbook was funded from SSC-SD as part of ONR 321 efforts. The diffraction work was done at Oak Ridge National Laboratories in cooperation with the PMN Maturation effort [C3] of J.C. Hicks at SSC-SD Code D364. Since these are also part of Sensors and Sources, progress has been reported herein.

Additional related effort began in late FY97 as a subcontract under STTR N97T003 with K. Bridger of Advanced Signal Technologies "Frequency Agile High-Power-Density Transducers". Five graduate projects have also been partially supported by the New York State Center for Advanced Ceramic Technology and the New York State College of Ceramics. These projects concentrated on synthesis and development of materials for transducer related devices.

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